Magnetic Torque Converter - Rapid Clutch

Field of the Invention

The invention relates to power transmission devices such as gear reducers, clutches and motor transmissions and particularly to devices useful for powered watercraft vehicle drive systems and land vehicles.

Background

Energy efficiency is a major concern that affects nearly every aspect of society. Transportation in particular is a heavy consumer of portable energy through the use of gasoline, diesel or natural gas powered internal combustion motors. Most energy from a transportation fuel dissipates as heat because of inefficiencies during chemical energy conversion into mechanical work. A major inefficiency is the mismatch between a faster rotating motor shaft or gear and a slower rotating device that receives such energy such as a wheel of a car or propeller of a boat.

A variety of transmission systems have been developed to minimize these losses. Unfortunately, each system has its own inefficiencies and problems. For example, in the case of powered watercraft that employ a fixed gear ratio, energy is lost from friction in the reducing gear and also in the propeller of such drive systems because the small propellers used represent a compromise and rotate at a much higher than ideal rate to push water efficiently. Ideally, a fast rotating motor with a high power output and with shaft speed of about 3,000 or 4,000 rpm should be geared down to a much slower rpm of a few hundred rpm, but with higher torque as needed to push water with a (preferably) large, slowly revolving propeller. Inexpensive gears and transmissions generally are not available for such high ratio speed changes. Accordingly, modern pleasure watercraft at low to medium speed generally are operated at lower than desired efficiencies.

David Geer has described this low efficiency problem of moderate speed watercraft (Propeller Handbook page 79) as "[f]or a given horsepower, the slower the shaft RPM and the larger the diameter the more efficient the propeller will be. This is true for every installation, unless the boat speed will consistently be above 30 or 35 knots. Accordingly, in selecting a propeller you should always start with the largest diameter possible for the given hull, and work from there.......Draft limitations, hull shape, and tip clearances.....are nearly the only factors that should cause you to consider a smaller diameter for slow-to-moderate speed craft. Another practical limitation is that while reduction gears with ratios as great as 6 or 7 to 1 are available for larger marine engines of, say over 250 hp (185 kw). standard reduction gears......are seldom available with ratios larger than 3 to 1..." According to this reasoning, a highly efficient and simple gear reduction of greater ratios approaching 10 or even 20 fold would give great benefits for many watercraft but is not readily available for regular watercraft.

A related problem is the need to rapidly stop a propeller, conveyor or other equipment upon detection of an unsafe condition. For example, a spinning propeller poses great hazards to swimmers and other waterlife. A rapid propeller stop system, is highly desirable but generally not considered because of the extreme difficulty in rapidly stopping a propeller. A limitation in this regard is that most propeller shafts are permanently fixed to a motor, either directly or indirectly through reduction gearing and rapid stoppage would overstress the drive system, due to the inertia of moving parts. Although not generally appreciated, a power transmission link between motor and propeller that both provides a high rotational speed change and the ability to rapidly stop a connected propeller would potentiate technological advances in electronic propeller guard systems. Unfortunately, such system generally is not available.

A large variety of gear reducers, clutches and other power transmission devices have been developed for many transportation machines. New types of clutches have evolved particularly for fans and air conditioners on cars and trucks and have provided incremental but highly desirable efficiency improvements for some applications. For example, a series of patents from Larry Link describe an electric clutch that electromagnetically disengages a fan as needed to minimize drag on an engine when

the cooling fan is not required. See, for example, U.S. Nos. 6,129,193; 6,230,866; 6,331,743 and 5,947,248; which teach the use of radially disposed electromagnets and a concentric set of pole pieces separated by an air gap. The torque transfer is modulated by controlling electric power to the multiple radially disposed electromagnets. This system promises to overcome frictional losses engendered by the widely used viscous clutch systems. However, the Link device appears to generate a considerable amount of heat, the electromagnets generally are rotating and need an electrical supply through a slip ring, and the entire system requires numerous parts. Furthermore, the energy efficiency of the Link system, which is notable by its omission from the copious documents that describe this technology, apparently is low. This view is supported by the Link disclosures, which emphasize multiple features that generally had to be added to remove heat buildup from the frictional losses, which again indicate that the system is inefficient.

Magnetic systems have been described for coupling other rotating axles as well. Masberg et al. (U.S. No. 6,149,544) teaches a coaxial (rotating cylinder within a rotating cylinder) dual electromagnet system that offers a stator body and a housing, which in some embodiments resembles a motor that couples two axles as a magnetically controlled clutch. This system is complex and generally requires a three dimensional magnetic assembly that maintains close tolerances in a dimension along the axis of rotation. Magnetic fields interact that are perpendicular to the rotational axis. The device is not unlike that of a regular induction motor, with the armature connected to a first axle and the field coil rotating and connected to a second axle.

Another interesting coaxial electromagnetic coupler is taught by U.S. No. 5,565,723, which emphasizes an internal electrical feedback to obtain a desired torque speed characteristic. The apparatus taught in this patent also uses two coaxially oriented rotable parts with inner and outer cylinders of electromagnets that exert magnetic coupling forces, which are perpendicular to the axis of rotation. This system as well appears very complex, and has slip rings to apply electricity to moving electromagnets. Such complexity is undesirable, particularly for applications in the

marine environment, where exposed electrical connections and conductors need to be marinized.

Despite a wealth of technology in the automotive and related arts, transmissions that provide high gear ratios and inexpensive, durable rapid acting clutches are not widely used for regular pleasure watercraft and other applications such as screw conveyors, elevators and related devices. In the case of watercraft, durable and cost competitive gear reducers of gear ratios less than 4 to 1 generally are used and rapid disconnect of propellers from the drive train is not carried out because of technology and cost limitations. While not recognized as such, these limitations are taken for granted and specific watercraft installations are optimized with inherent built in equipment limitations. For example, a specific boat with a specific boat motor generally is matched with a specific propeller that meets a selected criteria for best torque, motor speed, and motor output for a single optimum boat speed. Consequently, most drive systems are limited to a single gear reduction ratio and a single optimum propeller / boat combination that is chosen partly based on such a specific combination.

Similar limitations exist for other applications such as conveyors. Any device that provides greater flexibility in torque conversion between an upstream driving axle, such as a crankshaft or other drive gear and a downstream axle, such as a propeller shaft or other gear would advance the art of mechanical energy conversion by allowing a broader range of conditions for optimization. In the example of a torque converter for a propeller driven watercraft, better optimization of boat speed for optimum efficiency, and motor or motor conditions would be possible if a suitable torque converter were available that was efficient over a wide range.

<u>Summary of the Invention</u>

Embodiments of the invention provide gear reductions and torque conversions for a variety of equipment such as watercraft, other vehicles, screw drives, conveyor movements, and elevators, and directly thereby alleviate the problems noted above. Improved fuel efficiency, improved speed performance and improved flexibility for using effectors such as propellers, screws and gears are made possible by embodiments.

Embodiments also provide the ability to rapidly stop a machine or effecter such as a propeller and potentiate the use of electronic propeller guard systems. Other embodiments provide motor starters, generators and regeneration in combination with power sources such as internal combustion engines.

One advantageous embodiment is an axial connector or magnetic torque converter comprising a first rotating shaft with a flanged end that contains one or more magnetic field responsive materials (e.g. a paramagnetic substance, ferromagnetic substance, or magnet); a second rotating shaft with a flanged end that contains one or more magnets; and a bearing between the first shaft flanged end and the second shaft flanged end that allows independent rotation of the first and second flanged ends along a common axis; wherein magnetic field(s) from one flanged end to the other exerts a tugging force that transmits rotating force from the first rotating shaft to the second rotating shaft and optionally holds the two flanged ends together. Another embodiment is a self aligning axial connector or torque converter that transmits rotational force between two shafts, comprising a first coupler that connects to a first rotating shaft and that comprises one or more magnets or magnetic field responsive material; a second coupler that connects to a second rotating shaft and that comprises one or more magnets; and a bearing between the first coupler and the second coupler, wherein the magnetic field(s) across the first and second couplers optionally holds the two couplers together and the magnetic field(s) orient such that maximum magnetic attraction occurs when the couplers are located at the center of their rotating axes.

In another embodiment a magnetic torque converter with flanged ends as described here further comprises one or more electromagnets that exert a force that affects the coupling force, (magnetic force between the flanges) and thereby controls the transmission of force from the upstream spinning axle to the downstream spinning axle. In an embodiment at least one electromagnet coil surrounds at least one spinning magnetically response axle and imparts a magnetic field to the axle and to connected parts, such as a flange, thereby modulating the torque transfer. In yet another embodiment one or more non-rotating surfaces in magnetic contact (i.e. close enough to exert a magnetic force) to one or more flanges form an electromagnet and influences

the torque transfer this way. In yet another embodiment at least the downstream axle (axle that receives rotational force through the magnetically coupled device from the upstream axle) or upstream axle has one or more magnet(s) attached that are influenced by application of magnetic field from a fixed electromagnet outside the axle and that forms a braking mechanism wherein activation of the fixed electromagnet exerts a force on the spinning axle/permanent magnet, thereby slowing the spin.

Yet another embodiment is a torque converter or axial connector that acts as a starter motor for a connected internal combustion engine, comprising a torque converter or axial connector as described herein and a high current starter circuit electrically connected to one or more electromagnets, wherein the starter circuit activates the magnetic field of the one or more electromagnets to turn the internal combustion engine. Yet another embodiment is a torque converter or axial connector that acts as a power generator, comprising a torque converter or axial connector as described herein and a power consuming circuit electrically connected to one or more electromagnets, wherein rotation of one or more magnets within the torque converter or axial connector induces an electrical signal within the one or more electromagnets and the electrical signal is dissipated in the power consuming circuit. Yet another embodiment is a powered watercraft that comprises at least one motor and at least one propeller, the watercraft further comprising a torque converter or axial connector.

Yet another embodiment is a kit for adding a magnetic torque converter or axial connector to a watercraft, comprising a package, a magnetic torque converter or axial connector as described herein within the package, and one or more mechanical parts for installation. Yet another embodiment is a method of commercial research and development of watercraft propulsion systems, comprising providing a torque converter or axial connector as described herein, and connecting at least one rotation axis of the torque converter or axial connector to a motor. Yet another embodiment is a method of improving the performance of a watercraft, comprising providing a torque converter or axial connector as described herein, and connecting at least one rotation axis of the torque converter or axial connector to a motor. Yet another embodiment is a method of increasing the ability of a company in the marine field to obtain investment capital from

a prospective source of capital, comprising adding a description of a torque converter or axial connector as described herein to a business plan and providing the business plan to the prospective source of capital.

Description of the drawings

Figure 1 shows a side view of parallel flanges perpendicular to attached axles.

Figure 2 shows a side view of parallel flanges that are not perpendicular to attached axles.

Figure 3 shows representative placement of magnets with opposing poles facing each other.

Figure 4 is an end view of a flange, with a single bearing and 8 magnets.

Figure 5 is an end view of a flange with two bearings and two rows of 5 magnets each.

Figure 6 shows placement of permanent magnets according to an embodiment.

Figure 7 shows placement of a racetrack ball bearing on one surface according to an embodiment.

Figure 8 shows more detail for the junction of a magnetic transmission.

Figure 9 shows some representative basic parts for an embodiment.

Figure 10 shows placement of an electromagnet according to an embodiment.

Figure 11 shows placement of shaft coupled magnets and their controlling electromagnets according to an embodiment.

Detailed Description of Desirable Embodiments

In a desirable embodiment, two rotating surfaces, each with an attached axle, may be kept apart by a small distance via a bearing, and, if each surface comprises at least some magnetically responsive material and at least one contains a magnet (which

may be that magnetically responsive material), the magnetic field across the small distance can transfer rotation force from one axle to the other. Many variations of these scheme may be used. For example, a bearing such as a thrust bearing may hold the surfaces apart at a defined distance, a mechanism such as a spring, another magnetic field, or any other magnetic field control device may be used to control the magnetic field between the surfaces (by adding to, subtracting from the magnetic field, by altering the spacing between the surfaces, by addition or removal of magnetically responsive fluid between the surfaces, etc), and thus control the torque transfer between the attached axles to form a variable ratio transmission. One or more permanent magnets may be included, particularly on the periphery of a rotating surface, to establish a magnetic field between the surfaces. The magnets may be round, an irregular shape, or other regular shape and may comprise for example, 1 to 100 percent by weight of a flange, desirably at least 3, 5, 10, 20, 25, 30, 40, 50, 60, 70 percent by more, per weight of the flange (not including the axle weight). An electromagnet may be used, in a rotating part or at a fixed position to a rotating part, to modulate the magnetic coupling between the surfaces. The electromagnet may be pulsed with a very high electric current for a short time and thus temporally disengage the surfaces from each other or weaken the coupling between them.

A most desirable embodiment of the invention exploits the inherent constant torque of a magnetic coupler as described herein, for clutching and/or variable ratio transmission applications that do not require high starting torque. Watercraft propeller drive systems, elevators, screw conveyors and the like, for example, have greatly differing torque requirements from that of land vehicles, which often require motors and transmissions that can handle high starting torques. Generally speaking, the transmissions, clutches, and torque converters developed for the automobile industry are designed for high torque at low starting speed, and lower torque at high speed. Many of the reviewed devices are designed for the auto industry and generally include features and complexity associated with high starting torque. In contrast, the torque needed for a boat propeller starts low and, in many instances gradually increases with increasing rpm.

In an embodiment, one or more magnets are oriented to direct their fields across the space between two rotating flange surfaces and may be positioned to couple mechanical force between two axles through that space. The junction space in some embodiments is perpendicular to the axis of rotation and often comprises a large flat surface. Furthermore, by addition of one or more bearings at the surface it was found that surfaces on either side of the space may be held together by magnetic fields while allowing independent rotation. It was discovered that this arrangement is surprisingly useful for the torque requirements of powered propeller driven watercraft and other machines such as screw conveyors. In an embodiment, magnets can be used that have fields oriented perpendicular to or at another angle with respect to the rotation axis. In many embodiments, the delivered rotational force to a downstream axle such as a propeller shaft starts out as low torque at low rpm and increases gradually at higher rpm (e.g. up to 10%, 25%, 50%, 100%, or 200% over the useful rpm range). Changing the propeller (or other downstream energy absorber) alters the desirable torque vs rpm relationship. Accordingly, a magnetic arrangement as described herein can more suitably match loading torque for higher motor use efficiency. The transfer of power across a junction as described here can match the power needed to drive (for example) a propeller better than that supplied by many other devices. In a desirable embodiment the magnetic field across the distance between the flange surfaces is altered to adjust the torque transfer between the two axles.

Most desirably a torque converter or axial connector comprises a configuration of two rotating axles connected by magnetic field coupling across a junction between the ends of the axles that are separated by one or more bearings that allow independent rotation of the two surfaces perpendicular to the rotating axis. Most preferably, in easy to manufacture embodiments, each axle end terminates in a wider flange that has one or more magnets within it. By "wider" is meant that the average diameter of rotating surfaces that are perpendicular to the rotation axis are wider than either axle. Preferably the average surface diameter is 1.5 to 20 times the average axle diameter, more preferably between 2 to 10 times and more preferably between 2.5 to 5 times the axle diameter. One or more magnetic fields of one polarity are thereby established in a first flange of a first axle and one or more magnetic fields of a different polarity are also

established in a second flange of a second axle. Desirably, the flanges have major surfaces that face each other and each oriented within 85, 75, 60, 50, 45, 35, 30, 20, 15 or even less degrees away from the perpendicular to the rotating axis. In other embodiments the magnets are oriented radially and the flanges are not perpendicular to the axes but concentric (at least part of each resides as a sleeve within the sleeve of the other) with each other. Thus, the flanges may assume more complicated three dimensional structures that have magnetic attracting surfaces or localized points in close proximity to each other. By positioning the two flanges together, rotational movement in one flange is transmitted into rotational force in the other. One or more bearings may be placed between the flanges to allow them to rotate past each other with low friction, and thereby allow torque conversion. Preferably, when used in a watercraft or other device that does not require a high starting torque, a reduction in rotation speed occurs, along with change in torque.

Bearing(s) Sandwiched by Two Axle Surfaces with Opposing Magnetic Fields

One embodiment comprises two axle surfaces that are held together by one or more magnetic fields. To maintain freedom of rotation the surfaces contact one or more bearings at the junction. Preferably one large circular race trace bearing is used and the magnetic field coupling (force per unit surface area) is greater outside (further away from the axle) than inside the circular bearing.

An axle may be any shape but typically is rod like and usually between 0.1 to 8 inches in diameter. In many watercraft applications the axle is between 0.2 to 3 inches in diameter and more desirably between 0.4 and 1.25 inches diameter. The axle may be of any material such as stainless steel, aluminum, aluminum alloy, titanium, strong polymer, deldrin and the like. A low mass high strength polymer or composite such as glass or carbon fiber filled epoxy, aluminum, aluminum alloy or the like is particularly desirable for an axle that is connected to a propeller as part of an electronic propeller guard system. Desirably the material is not paramagnetic. Use of a low mass downstream axle provides less inertia for more rapid stopping of the propeller. The axle may comprise or may be connected to a torsional damping device. Devices, such as

those reviewed in U.S. No. 6,508,713 and the new device claimed in that patent, are particularly useful in combination with embodiments of the invention.

The end of the axle in many embodiments is widened, such as into a flange having at least one surface portion that is perpendicular to the axis of rotation. The flange preferably is round with a center at the axis of rotation and typically is between 1 to 20 inches, preferably 2 to 12 and more preferably between 3 to 9 inches in diameter. The flange can assume a variety of shapes. Figures 1 and 2 depict some examples of shapes. As seen in Figure 1, the flange may have a major surface that is perpendicular (i.e. within 80 to 100 degrees, preferably 85 to 95 degrees, more preferably 88 to 92 degrees, yet more preferably 89 to 91 degrees angle) from the axis of rotation, and both axles share the same rotation vector. Typically two of such flanges are combined with opposing surfaces facing each other, are held together by opposing magnetic fields, and allowed to rotate by one or bearings within each or between them. Such bearings may be regular precision bearings. Figure 1 shows flange 10 with axle 15 of a first face plate coupled to flange 17 with axle 18 of a second face plate. In another embodiment shown in Figure 2, the flanges have matching (parallel) surfaces that depart from this angle and may even appear cone shaped. As seen in this side view, flange 20 has attached axle 21 and flange 22 has attached axle 23. An angular thrust bearing is not shown. Figure 3 shows some representative magnet placements. Magnet 31 on flange 30 couples with magnet 32 on flange 33. Also shown here are magnets 34 and 35 on concentric portions of these flanges. Other magnets and the rest of the flange structures are not shown in this very simplified side view.

Although conformations, sizes, and placement of individual magnets are exemplified in the text and figures presented here, it is emphasized that a wide variety of conformations, sizes, placements and numbers of magnets may be used to create torque transfer between two flanges that rotate on a common axis and with parallel surfaces, as will be appreciated by a skilled mechanical engineer or physicist axles. In a particularly desirable embodiment a flange comprises a magnetic field responsive material in flange 410 (see Figure 4a) made out of steel , half of bearing 420 in the flange, a second flange 430 having the other bearing half (not shown) and some

magnets within flange 430 that exert a force upon the steel when the two flanges are assembled (see side view of assembled device in Figure 4b).

In another embodiment shown in Figure 4c, a first set of magnets 471 are placed closer to the center of flange 472 inside large bearing 473 and a second set of magnets 474 are placed outside of bearing 473. In an embodiment inner magnets 471 are oriented to exert magnetic fields perpendicular to the flange surface and primarily hold the two flanges together while outer magnets 475 are oriented with fields perpendicular to the flange surface or at least partially parallel to the direction of rotation. The term "at least partly parallel to the direction of rotation" means at least 5 degrees, 10 degrees, 15 degrees, 20 degrees, 35 degrees, 45 degrees, 50 degrees, 60 degrees or even more away from the rotation axis vector. Figure 4d shows magnet 481 in a portion of flange 482 such that end 483 breaks the surface of flange 482 and bored bole 484 angles down at an angle, to allow the magnetic field to tug on the opposing flange (not shown) during rotation. In another embodiment, a rod shaped magnet is inserted into a hole that is oriented parallel to the rotation axis. The magnet may be manufactured with north-south poles that are oriented at least partially away from the long axis of the magnet. A magnet as described herein may be prepared by pressure fitting neodymium iron cobalt (or other material such as magnetizable ceramic) particles into a shape under influence of a strong magnetic field. In another embodiment a magnet such as a rod magnet may be manufactured with magnetic fields that emerge parallel to the magnet surface (ends of the rod) but then at least one end face is machined to an angle such that magnetic force lines emerge from the surface in a non-perpendicular direction. In a desirable embodiment rod magnets are inserted into round holes of the flanges and may be fixed by an adhesive such as an epoxy. In another embodiment an entire flange or concentric (annular) region(s) of a flange is a permanent magnet. In a related embodiment two or more regions are magnets and have polarities opposite each other, and form a combined magnetic field through the junction into the opposing flange by virtue of this.

In some embodiments that use this conformation, the two axles have self-centering capability because movement of one or both flange surfaces away from the

center axis will result in a mechanical force back into alignment. For this embodiment the use of angular contact bearings, chosen to accommodate the angle of contact between surfaces is particularly desired. Most preferred are conical matching surfaces with nominal contact angles of 15 degrees, 25 degrees, or 65 degrees, as many angular contact bearings are available for this angle.

The flange may have one or more ball thrust bearings such as radial ball bearings that occupy deep grooved circular space(s) on the surface of one or (preferably) both flange surfaces. The inside diameter may be, for example, between 0.5 and 15 inches, preferably between 1 and 10 inches. Permanent magnets may be mounted on the inside and/or outside of a bearing race. Although permanent magnets are exemplified in the figures, electromagnets also can be used in combination or separately on one or both flanges, and slip ring(s) or brushes may be used to supply power to the electromagnet(s). Furthermore, one of the flanges may even lack a magnet and instead comprise iron or other paramagnetic material that is attracted to magnet(s) on the opposite flange. Figures 4 and 5 of provisional application filed 2/06/03 show some representative placements of one or two ball thrust bearings with multiple magnets. Figure 4 shows location of bearing 41 and magnets 42. Figure 5 shows location of bearings 51 and 52, which share the load caused by magnets at positions 53 and 54. In one embodiment a magnetic force director such as iron is located at each of position is 53 and 54, and pairs of 53 with 54 are coupled together by a cylindrical magnet extending from each 53 to a nearby 54. The fields at 53 are all one pole and the fields at 54 are all the opposite pole. For high power embodiments two radial bearings are particularly desirable. In each case, the flange material, thickness, and magnet type (strength) should be chosen so that the magnetic field pull on the flange and extended use does not deform the flange surfaces but maintains a small air gap (average gap typically 0.001 to 0.25 inches, preferably between 0.01 to 0.1 inch) between the opposing magnets.

In one embodiment, two shaft ends are constructed having diameters between (in centimeters) 1 to 5, 2 to 10, 3 to 15, 4 to 30, 5 to 25 or even more than 25 centimeters in diameter. Tube, channels, or holes are drilled from the side away from

the face to make suitable openings for insertion of magnets, such as samarium cobalt, ferric, or another stronger magnet. Conveniently, two complementary shaft ends are positioned on opposing sides of a low friction bearing, or bearing assembly, and alternately, in turn, magnets are slipped into the opposite sides, which gradually increases attraction between the two sides. When all magnets are in place, a nominal pull exists that provides a nominal torque transfer across the junction. Further addition of an electromagnet allows further addition or subtraction to the magnetic pulling force across the junction. Figure 6 is a perspective view of a representative magnet placement for one shaft end. Shaft 410 is connected to end 420, which is a solid block of metal with drilled out spaces 430 that hold cylindrical magnets. The holes do not extend the entire length of the solid block, to prevent the magnet from pulling out the opposite side due to attraction from a complementary shaft end with magnets of an opposite polarity. Figure 7 shows a representative race track ball bearing 510 on a flat surface 520.

During use for some embodiments, the upstream and downstream shafts should be mounted in a fixed position and the downstream shaft further should include a thrust bearing, to accommodate propeller loads and back forces. Other vibration dampening devices and materials may be used to minimize the imposition of motor and propeller forces onto the transmission joint.

In many embodiments a low friction bearing is used to hold the faces of the complementary ends in close proximity to allow magnetic coupling by their magnetic fields. See for example side view of bearing 270 in figure 8, bearing 160 in figure 9. The faces may be flat/planar with respect to each other and may consist entirely of flat surfaces that are perpendicular to the axis and with simple bearings as shown in these figures, but also may have very complex shapes with multiple bearings at different locations of contact. However, in other embodiments, the faces are more complicated and may assume ridges on a flat surface, or other structures as may be desired to optimize other parts, such as placement and design of a low friction bearing. In a simple embodiment represented in the figures, the ends are flat and perpendicular with respect to the axis of their shafts and a round race track bearing with multiple balls is

attached to one or both facing surfaces. In an embodiment the magnetic fields are arranged with greater force lines towards the center and lower force lines towards the periphery. This allows self alignment of the junction. If one shaft drifts out of center, the stronger magnetic attraction available at the center tends to pull the shaft back into alignment.

Magnets

Magnetic fields used for embodiments of the invention may be created by permanent magnet(s), electro magnet(s) or combinations of permanent magnet(s)and electromagnet(s). For many low cost embodiments one or permanent magnets are particularly desirable and can be made from a variety of materials and in a variety of shapes. For example neodymium iron boron, samarium cobalt, alnico, ceramic, and/or ferrite are suitable for permanent magnets. Magnets may be physically inserted into a device. In many embodiments magnets are inserted into rotating parts, by screwing, placing into holes, bolting, gluing, or the like. In a desirable embodiment a powered composition of rare earth magnetizable material such as neodymium ion boron is mixed with an organic material that polymerizes into a solid and the solid may be screwed in or otherwise mounted on a device as described herein. In another embodiment an entire part of a device, such as a rotating surface comprises magnetic material.

In some embodiments a paramagnetic material such as iron is used to direct the magnetic lines of force from one or more permanent magnets. This is particularly helpful when the individual magnetic fields of separate magnets are to interact, preferably by attracting, with magnetic field(s) of magnet(s) attached to the opposite axle. In was found that localizing magnetic fields form magnets associated with each axle allowed greater torque transfer between the axles. Without wishing to be bound by any one theory for this embodiment of the invention it is thought that when the magnetic fields of multiple magnets associated with one axle merge to act as one large magnet across a greater surface area perpendicular to the axis of rotation, an opposite attractive magnetic force that moves over that same area does not experience any position dependent attraction. On the other hand, when a localized magnetic north pole

moves across the individual fields of several localized magnetic south poles, each interaction represents a separate attractive tug, which increases the attractive force experienced during rotation.

Electromagnets may be constructed using a variety of materials and techniques as are known in the art. Preferably, one or more electromagnets, if used, are fixed in location and not supplied electric power through a moving part such as a brush or ring assembly. Electromagnet(s) may be fed a variety of electric signals for pulsing, stopping and other activities. An electromagnet may create a field that joins the field of a permanent magnet, and thereby modulate the magnetic field across the junction.

<u>Bearings</u>

A variety of bearings may be used to alleviate friction between the ends of the axles. For example, ball bearings constructed of steel, silicon nitride, ceramic, or other material may be used within channels, or other spaces as are known to skilled artisans. Most preferred are thrust bearings comprised of round retainers that hold balls, and having hardened washers on each side. To improve wear and minimize the effect of magnetic fields on the bearing, ceramic balls are particularly useful. Nylon or phenolic retainers also are desirable. Most washers in this type of application are hardened steel or stainless steel and would be sensitive to strong enough magnetic fields. A non-para-magnetic material (such as a plastic washer) may be inserted between the washer and the flange body to minimize the effect, if desired. Regular ball circle / washer assemblies are preferred over banded thrust bearings due to their greater ability to absorb thrust stresses. Bearings may be used, for example in flat race, angled, flat-seat thrust ball, grooved race, double acting, self aligning configurations. Roller bearings may be very useful for instances where high radial loads are experienced. Thrust ball bearing assemblies may be obtained from a variety of source, such as Scheerer Bearing Corp. (Horsham, Penn.) or The Barden Corporation (Danbury, CT) the latter of which offers excellent literature that teaches how to select and use a suitable bearing.

The friction from two or more flange surfaces may be alleviated by the use of Teflon or other slippery material as an intermediate substance between the surfaces. A

good material is high molecular weight polyethylene, particularly cross linked by radiation to harden the surface and improve wear properties. The use of a simple layer of slippery material is particularly useful for low cost rapid acting clutch embodiments, where the surfaces slide past each other only for very short times, and a change in torque created by constant differential rotation of the two axles is not employed. That is, for rapid clutch activation whereby disengagement occurs very infrequently such as in an electronic propeller guard, a simple low friction surface may suffice.

An angular contact thrust ball bearing or cylindrical roller bearing assembly is particularly desirable for contacting opposing flange surfaces that are not perpendicular to the rotation axis. Angular contact thrust ball bearings allow, for example, the use of conical flanges, which can be self aligning, and allow more play in the alignment of the two axes.

A center pilot shank optionally may be used to keep the opposing flanges aligned on the same rotation axis. The shank may be for example a stainless steel pin that is inserted into a hold or sleeve or other tube, in the center of rotation axis of both flanges. A bearing such as a sleeve bearing or roller bearing may be used to minimize friction of the shank. Use of a pilot shank is particularly useful because the magnetic force that holds a double flange assembly together can vary and a negative thrust might exceed the attractive forces, which, even momentarily, may pull the flanges apart. For example, when used within a boat propulsion system a device as described herein may be suddenly reversed for reverse propeller thrust. In such case, the downstream axle towards the propeller may exert a pull on the device, which would counteract magnetic forces holding the double flange assembly together. Having a center pin at the rotational axis will allow some variation in air gap between the flanges without losing the center positioning of the flanges. In this embodiment, when using a circular thrust bearing it is helpful to have commensurate tension in the bearing assembly to allow this movement without damaging the bearing. A polymeric, rubber or other compressible material may be sandwiched between thrust bearing washers and the adjacent flange surfaces to accommodate this.

Magnet Orientation and Placement

Magnets may be placed and oriented in a variety of positions depending on the use. An axial connector, which has fixed magnetic fields from permanent magnets provides a nominal mechanical coupling that may be modulated by an electromagnetic clutch, or a variable speed reduction for a given torque and generally is not electrically adjustable. A torque converter, as on the other hand as termed herein, comprises a continuously adjustable torque transfer and may have one or more electromagnets that generate magnetic fields that influence the magnetic field(s) of rotating magnets to alter the transfer of rotational power.

In one embodiment a flange surface comprises a magnetic material throughout, which presents a single large magnetic field that extends throughout the entire surface. This material may be for example, particles of rare earth magnetic material in a polymer matrix, or the material may be a magnetic ceramic formed in the shape of the flange surface. In another embodiment one or more permanent magnets are mounted in a paramagnetic material that makes up the flange surface and which delocalizes the magnetic lines of force throughout the entire surface. In yet another embodiment magnets are present on only one of the two flanges and paramagnetic material such as iron is present without any magnets in the second flange. The north-south orientation of the magnetic field that emerges from the flange surface made thereby may be parallel to the rotation axis but most preferably is at least partly away from the parallel by at least 5, 10, 15, 20, 30, 45 or even 60 degrees of angle. In an embodiment the magnetic fields are oriented away from the rotation axis vector and at least partially along the vector (ie. not entirely perpendicular to) of the direction of rotation. This is because, for that embodiment, the torque transfer is much greater if the magnet pulls in the direction of movement. Accordingly a most preferred embodiment utilizes magnetic fields that contribute at least some pull in the desired direction. In some embodiments it is desirable to have the magnetic fields pull the two flanges together and in an embodiment the field is oriented in between to allow pulling of the flanges together while partially pulling in the direction of movement.

In many embodiments the magnet(s) are oriented so that one pole is directed to the opposite flange across the air gap. A shaped piece of paramagnetic material such as iron may be used in contact with or proximity to a magnet to direct the lines of force from a pole across the junction. However, in a particularly desirable embodiment both fields of a magnet are directed across the flange junction, either by shaping the magnet accordingly (e.g. by making the magnet in a horseshoe shape with the ends facing the junction) or by using paramagnetic force directors. As described above for Figure 5, magnets may be inserted into positions between north pole directors and south pole directors. The directors exert both south and north pole fields away from the flange surface.

In an embodiment multiple magnets (or their fields) are used and, for a given flange, are equally spaced towards the periphery of a flange to evenly distribute their mass and attractive forces to minimize vibration. Figure 10 shows in side view, two thick two flanges 301 and 330, which are used together, that have 8 magnets each (not shown). As the flanges rotate at different speeds, there are 8 positions along a 360 degree rotation wherein the pull between flanges is maximum. In an embodiment, electromagnet 310 nearby is oriented and energized with a pattern of electrical pulses to minimize the 8 pulses per change in rotation between the two flanges to minimize vibration. In yet another embodiment, one or more magnetic field detectors such as a hall device are positioned nearby and sense the difference in rotation rate, thus inferring information about the change in rotation rate between one axle rpm and the other axle rpm.

In many embodiments it is highly desirable to maintain magnetic force attraction between the opposing flanges. For this reason, magnetic opposing force should exist at multiple equidistant locations of a flange at all times. One way to achieve this is to have magnetic force in the center of the flange, perhaps inside the bore area of a round thrust bearing, if used. Another way is to make the entire flange at least partly magnetic and create attraction throughout the surface area at all times. In this case, additional points of high magnetic attraction at extreme periphery of the flange is desirable to obtain greater torque transfer. Yet another way is to use both poles of a magnet so that the

north pole fields are directed at equally spaced points at one distance from the axis of rotation and the south pole fields are directed at equally spaced points at a second distance from the axis of rotation so that when the attraction between opposing fields for one concentric line of fields is at its maximum the attraction between opposing fields for the second concentric line of fields is at its minimum, and vice versa. In one embodiment an inner band, comprising a single magnet or individual magnets is arranged in a ring around the center axis of the flange.

In an embodiment, magnets are arranged on opposing surfaces of both flanges so that their magnetic fields pull each other. In this case, the magnets on one flange may not all line up (opposing magnets all opposite each other) at one position during rotation. Such synchronous operation is desirable where a discrete torque shift is desired. For example, if 4 magnets are used on both sides at four equidistant locations, then at times of very low resistance to the output shaft rotation, the two flanges will rotate together and the rpm ratio of both shafts will be 1. When a threshold resistance is exceeded, the partnered magnets will uncouple, and the downstream flange will rotate more slowly, and generally receive much less power. In many situations, particularly for watercraft, this torque shift is not very ideal, and asynchronous operation is preferred. The term "asynchronous," as used herein, means that the magnets on the upstream (motor driven) flange do not match up exactly with the magnets on the downstream (power absorbing) flange. Instead, there is always one or more magnets that is not maximally opposing a magnet, with maximum magnetic attraction at any given time.

One way to achieve asynchronous operation is to have different numbers of evenly spaced magnets on each flange. For example, one flange may have 5 magnets at 6 inches away from the rotation axis and the other flange may have 7 magnets at 6 inches away form the rotation axis. All five magnets of the first flange are not perfectly positioned opposite five magnets on the other flange at any time. A particularly desirable asynchronous arrangement is to have two or more concentric rows (a row is a set of magnets at the same distance from the rotation axis) on both flanges such that when a first row of magnets line up with the opposing row from the other flange, the

second row of magnets do not line up. If both flanges have the same number of magnets positioned the same way in two such rows, a partly double synchronous operation may result such that transfer of power, as seen by a rpm vs horsepower curve, tends to have two plateaus. The same phenomenon can be obtained for three or more rows as well. This is desirable for some embodiments where two different (or more) set torques are desired, without having to use control circuits for electromagnetic fields to adjust torque. A skilled artisan can design combinations of magnets that yield different kinds of asynchronous operation and further details are not provided due to space limitations. For driving propellers on watercraft however, a fairly asynchronous operation often is desired. Of course, one or more electromagnets can be pulsed so that their field(s) counter the tendency towards asynchronous operation, as well as establish desired patterns of synchronous operation. In doing so, it is helpful to detect rpm of both shafts in real time, and to have a control circuit and/or software analyze the parameters and control the electromagnet(s) accordingly.

In a preferred embodiment that provides lower cost one flange contains permanent magnets and the other contains a continuous large surface of magnetically responsive material that is not magnetized, around a rotating axis. Each permanent magnet exerts a constant magnetic pull on the magnetically responsive material because as the flanges rotate, a constant amount of magnetically responsive material exists in close proximity to the permanent magnet. In a simple embodiment according to this scheme the magnetically responsive material is a circular steel plate that rotates around the center of the plate and has an axle at the center.

<u>Torque conversion: a representative system</u>

One representative system, as shown in Figure 9, includes upstream shaft 110 attached at one end to motor 120. The other end of shaft 110 is magnetically coupled to shaft 130 via coupler 150. Shaft 130 has attached propeller 140. This figure does not show magnets but includes ball bearing 160 which keeps the metal surfaces of the two shafts from grinding on each other. The system may be in any possible orientation and generally can be used with any type of motor and propeller.

Figure 8 shows more detail of a representative coupler. This side view shows upstream (towards the motor) shaft 210 having an end 220 that faces a complementary end 230 of downstream (towards the propeller) shaft 240. Ends 220 and 230 in this example contain imbedded permanent magnets. Two magnets 250 are shown within end 220 and two magnets 260 are shown within end 240. In this example each set (within one end) of magnets are oriented with the same polarity, and the opposing sets are oriented with opposing polarities, which magnetically pulls the two ends together. A ball bearing between the faces of the two ends are kept apart through a small distance by a mechanism that may be, for example, bearings, such as ball bearings, bearings with a spring or other expansive device that pushes the faces apart, bearings elsewhere on the the shafts, and/or combinations of these. Figure 8 shows ball bearings 270 (which normally are mostly within a groove shared between the two flange surfaces) and the distance between the faces is made overly large for purposes of illustration.

<u>Continuously variable torque conversion system</u>

The magnetic coupling between upstream and downstream shafts may be modulated by one or more of a wide variety of techniques and contrivances. One method is to vary the spacing between the two faces, because magnetic field strength is inversely proportional to a factor (such as the cube) of the distance. A spring, piston, compressed fluid or other arrangement can be made to modify this distance, as will be appreciated by a skilled mechanical engineer with routine optimization. Another method is to modify the placement or permeability of magnetic field radially away from (or to) the axis of rotation. For example, a magnet, or its lines of force, may be moved further away from the rotational axis. If this is done for magnetic fields (and/or magnets) on both sides of the junction, then torque transfer may be increased, with concomitant alteration in rpm ratio. Another method is to modify the placement or permeability of magnetic field along the axis (closer to and/or further from the junction). By moving one or more magnets (and/or its field) closer to the junction a greater torque transfer will be possible. In a desirable embodiment, the centripetal force associated with higher

rotations pulls magnets, or magnetic field directors in a manner that decreases the magnetic attraction across the junction between flanges and effectively increases the rpm change, while increasing output torque at the downstream shaft. This is particularly desirable for use in watercraft, because the coupling (inverse of effective gear ratio) ideally becomes lower as the watercraft increases speed and the motor rpm increases.

Introduction of Electromagnet Control Field

A highly desirable way to modulate torque transfer is to include a (preferably fixed, non moving) electromagnet that can add to and/or subtract from one or more magnetic fields. Figure 10 illustrates in side view, one such embodiment where a single coil, shown as two lobes 310 are wrapped around downstream complementary end 330. The electromagnet may comprise one, two, three or many more separately controlled coils and may envelope the upstream side, downstream side, or both sides. An advantage of the downstream coil 310 shown in Figure 10 is that in addition to decreasing coupling of the propeller shaft from the motor shaft, this coil (or a portion of it) can be energized in a manner to allow electromagnetic braking of the propeller shaft, by interacting with permanent magnet(s) in the downstream shaft.

In yet another desirable embodiment, one or more preferably two electromagnet coils surrounding a moving shaft are located adjacent to one or more permanent magnets attached to a shaft, as for example, diagrammed in Figure 11. Here, upstream shaft 1110 is attached via optional magnetic torque converter 1120 to downstream shaft 1130 and propeller 1170. Immobile stops 1140 prevent excessive disengagement of the two flanges that make up torque converter 1120. Immobile stops may be for example a fixed bearing or a Teflon TM surface that prevents downstream shaft 1130 from moving too far to the right. One of the permanent magnets attached to the downstream shaft 1130 is shown as dark filled rectangle 1150. Electromagnet coils 1160 are located adjacent to and both upstream and downstream to magnets 1150. Coils 1160 are fixed and wound around a plastic sleeve on shaft 1130. Coils 1160 are

located at a position to impart maximum force onto magnets 1150 upon application of electric current.

Preferably during operation, the right hand coil 1160 creates a magnetic field that is opposite to the right hand side field of magnet 1150 and the left hand coil of 1160 creates a magnetic field that is the same polarity as the left hand side field of magnet 1150. During operation both electromagnets 1160 are energized together. The left electromagnet of this pair pushes magnet 1150 and thus shaft 1130 to the right. The right electromagnet of this pair pulls magnet 1150 and thus shaft 1130 to the right. In response, gap 1180 within torque converter 1120 becomes larger and the right side of 1120 may move to touch immobile stops 1140. In another embodiment activation of electromagnets 1160 modulate the torque transfer at 1120. A spring held mechanism for 1120 may be used. For example, a spring or other tensioning device may exist between the right side of 1120 and stops 1140. In yet another embodiment a further electromagnet, (or a portion of electromagnet 1160) is oriented close to the lateral surface above 1150 and acts further as a brake of angular momentum. In another embodiment an electromagnet such as electromagnet acts as an electricity generator and in yet another embodiment the electromagnet is used as a starter motor for an internal combustion engine. A skilled artisan after reading this specification and the drawings will appreciate yet further alterations, and space limitations preclude listing all such possible embodiments.

In another embodiment a paramagnetic axle attached to a paramagnetic flange has an electromagnet that affects the flange magnetic field. An example of this is a flat steel flange with an attached steel axle. Covering the axle near the flange is a sleeve (such as a plastic or aluminum tube, preferably with wall diameter less than 0.25 inch), optionally with lubricant, that allows rotation of the flange/shaft without rotation of the sleeve. An electromagnetic is made by winding wire around the sleeve. By impressing an electric current through the wire, the axle under the sleeve becomes magnetized, and transfers the magnetic field to the flange. Other materials and methods for modifying the magnetic field(s) at the flange surfaces will be appreciated by a skilled artisan based on these examples.

Fast Acting Clutch System

An electromagnetic field used in torque transfer is particularly desirable for devices and systems that rapidly disconnect the propeller from the motor. In this case, a suitable electric current of sufficient magnitude and polarity is switched or modulated onto one or more electromagnets so as to diminish the magnetic field(s) on one or both sides. In a desirable embodiment, the combined (merged) magnetic field from a permanent magnet measured at the surface of the opposing rotor is decreased by at least 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 97%, 99% or even more by action of a nearby electromagnet that is switched for this purpose. The electromagnet may be affixed to and rotate with one of the flanges, in which case electrical power must be supplied, for example, by slip rings, or brushes. More preferably the electromagnet is fixed and does not rotate. The "electromagnet" may comprise more than one coil of electromagnets that may be independently excited.

The action of pulsed electromagnets, according to an embodiment can significantly slow (decrease speed 90%) or even stop a shaft such as a propeller drive shaft within 1 second, 750 milliseconds, 600 milliseconds, 500 milliseconds, 400 milliseconds, 300 milliseconds, 250 milliseconds, 200 milliseconds, 150 milliseconds, 125 milliseconds, 100 milliseconds, 85 milliseconds, 75 milliseconds, 60 milliseconds, 50 milliseconds, 40 milliseconds, 35 milliseconds, 30 milliseconds, 25 milliseconds, or even 20 milliseconds. In a most desirable embodiment, two or more capacitor stored charges are discharged via a semiconductor switch such as a transistor or silicon controlled rectifier at two or more different time constants into one or more electromagnets simultaneously. Desirably the voltage of one capacitor stored charge circuit decays to one half its initial value within less than 50 milliseconds and the voltage of another capacitor stored charge circuit decays to one half its initial value after more than 50 milliseconds. The two or more discharged pulses allow both rapid acting and longer acting charges to develop a very fast magnetic field in less than 50 milliseconds, but also a longer time duration field of more than 50 milliseconds.

In another embodiment a magnetic field from one or more electromagnets acts to brake the downstream axle rotation. The electromagnet may have a dual purpose for both adjusting torque transfer through the junction and braking, or may be a separate electromagnet dedicated to braking. The electromagnet may still further serve as an electric generator, a starting motor or both. The braking action may arise from interaction between the electromagnet (attractive/repulsive, or both) and the permanent magnets in the flange or between the electromagnet and one or more permanent magnets elsewhere, such as on the axle connected to the propeller.

In this embodiment power from one or more electromagnets rapidly stop a spinning axle. One or more pulses of power energize electromagnets that pull on permanent magnets that are connected to one or more spinning axles. The permanent magnets in an embodiment do not participate in torque transfer between two face plates but are separate and connected to an axle. For example, two or more magnets may be imbedded to or attached to the surface of an axle, and may surround the axle arranged like staves of a barrel around the axis. One or more electromagnets, preferably just outside the ends (perpendicular to the rotation) are fixed and exert a force upon the axle magnets. Such fast acting electromagnetically controlled magnetic coupler is very useful for rapidly stopping an axle rotation and is preferred to implement an electronic propeller guard.

In a desirable embodiment, the two shafts are coupled synchronously such that their magnets are locked in place with respect to each other. A large electromagnetic pulse asserted into one or more electromagnets arranged near the flange magnets and/or near the axle magnet(s) at least momentarily decouples the two axles or pulls them apart by asserting a magnetic field against one or more permanent magnet fields. This allows at least a momentary decoupling and subsequent rotation of the drive shaft with respect to the driven shaft, for at least part of one revolution. When pulsed, the two face plates begin to rotate independently of each other. One or more further pulses may be asserted for continued decoupling. For example, a large electric pulse that decays with a half life of 100 milliseconds may be imposed on the electromagnet(s) at the same time as another large pulse that decays with a half life of 20 milliseconds, in

order to obtain both rapid initiation and more prolonged pulses. Still further, a steady (but lower current) DC voltage advantageously may be applied.

Preferably, the electric pulses arise from a silicon controlled rectifier controlled discharge from a capacitor. Firing the silicon controlled rectifier allows very rapid discharge of a very high amount of electricity through the electromagnet, which can a) decouples the opposing discs for a short time; b) pull the opposing discs apart via interaction on shaft magnet(s); or both a) and b). In an embodiment the surfaces move apart from each other. In a desirable embodiment, a bearing may be added to the other side of one or both surfaces, to keep them from separating too far from each other. Of course, other mechanical stops may be employed as will be appreciated by a skilled machinist.

While the magnetic field coupling weakens, the drive motor preferably starts to shut off. For example, when used with an internal combustion engine drive, sparks may be interrupted and fuel flow may stop. In an embodiment wherein the shafts are coupled via permanent magnets, the shaft uncoupling from the initial pulse(s) may last no more than a single revolution because the permanent magnets align themselves in position with each other again after 360 degrees (if one facing magnet), or 180 degrees (if two facing magnets as preferred) or even less rotation. In some cases, the rotation time is slow enough to allow shut off of the drive motor and the system stops during this short time. However, in an embodiment wherein the shafts have been rotating quickly, the electromagnet(s) may be pulsed again to alleviate the magnetic coupling between shafts for another time period. Optionally, a brake on either or both shafts may activate. In a preferred embodiment rapid pulse(s) to an electromagnet decouple the shafts momentarily to allow time for slow acting braking systems, such as friction brakes, and simple motor shut off, to operate.

This kind of electromagnet brake can be used on either or both sides of the coupling, and is most preferred on the driven (e.g. propeller) side. In an embodiment the same electromagnet(s) that decouple the two sides of the magnetic coupler also assert a braking effect on the propeller side shaft via magnetic interaction with magnets

on that shaft. One side of a decoupling electromagnet is near magnets on the propeller side and the other side of an electromagnet is near magnets on the propeller side shaft. In a desirable embodiment the braking occurs by interaction of fixed electromagnets driven by a rapidly discharging capacitor (controlled by a transister, IGPT transistor, SCR or the like) and the electromagnets may act directly on a shaft by pulling and/or pushing shaft permanent magnets in a direction along the shaft axis.

A most rapid and powerful electromagnet braking circuit is preferred. In order to achieve rapid uncoupling, a very rapid pulse is preferred. Maximum (instantaneous measurement) current flows preferably in less than 250 ms (milliseconds), less than 125 ms, less than 75 ms, less than 50 ms, less than 35 ms, less than 25 ms, less than 10 ms, less than 6 ms or even less than 3 ms. A major limitation with electromagnets is the amount of power that can be absorbed without overheating the wire. In a preferred embodiment, a super high power is pulsed, which exceeds the allowable steady state power dissipation of the electromagnet coil by at least 10 fold, 100 fold, 1000 fold or even at least 10,000 fold. Preferably, a large capacitor of at least 1000 microfarads, 10,000 microfarads, 25,000 microfarads, 50,000 microfarads, 100,000 microfarads, 250,000 microfarads or more at high voltage (at least 25, 50, 100, 200, 300, 500 volts or more) is kept charged up and then discharged into the electromagnet when a stop is called for. In another embodiment a low voltage (less than 12, 10, 6, 4, or even less than 2 volts) capacitor of high capacity (at least 1, 5, 10, 25, 50 farads or more) is used. High power versions of electronic flash circuits commonly used for flash photography are particularly desirable for energizing a coil.

The permanent magnets against which the electromagnetic field(s) interact to slow/stop an axle also are limited to the amount of impressed magnetic field that they can tolerate before becoming permanently demagnetized. Desirably, the amount and duration of impressed magnetic field from an electromagnet is smaller than that which can demagnetize a permanent magnet by 5% after 100 electromagnetic pulse events, more preferably less than that which can demagnetize the permanent magnet by 1% after 1000 pulse events, and even more preferably less than that which can demagnetize the permanent magnet by 0.1% after 1000 pulse events.

In a particularly desirable embodiment extremely high electromagnetic fields from a pulsed circuit are impressed onto one or more permanent magnets attached to a shaft and aligned with their north and south poles arranged parallel to the axis of rotation. The permanent magnet(s) optionally are reversibly attached such that pulling or pushing them up or down along the length rotation axis will result in a force on the shaft. By allowing their removal, the magnets can be replaced with fresh magnets after destruction of some of their magnetism by repeated use. This embodiment allows stronger electromagnet pulsing than otherwise can be used.

By pulsing for only a short time heating is minimized. Preferably, inductance is kept low to allow a high electromagnet current with short delay times, as for example described by RLC simulations presented at http://www.oz.net/~coilgun/mark2/rlcsim.htm. In an embodiment, either the same coil or another coil additionally is separately excited with a longer pulse time, to provide a longer duration decoupling. For example, a 20 millisecond pulse (90% of the total energy expended within 20 milliseconds) may be asserted for rapid action, but another 200 millisecond pulse having a long rise time is also used. By combining both a fast acting but very short pulse with a slow acting but longer pulse, both rapid decoupling and longer decoupling may be achieved. A desirable way to implement this embodiment is to connect one or more silicon controlled rectifiers (SCRs) with charged capacitor(s) with a blocking diode. Each SCR can be triggered together, particularly if their circuits have differing time constants, or separately to obtain both a faster acting pulse (lower inductance, lower resistance) and a longer acting pulse (higher inductance, resistance).

Another embodiment provides a system comprising a capacitor, capacitor charging circuit that can be as simple as a continuous connection to a power supply, an electromagnet, and a solid state switch such as a MOSFET, an IGPT or SCR that connects the capacitor to the electromagnet upon triggering. In the case of the electronic propeller guard embodiment, triggering may arise from a sensor that detects an object near the propeller. Of course, multiple capacitors, solid state switches, and electromagnets may be used in combination. Another embodiment is a container that includes the capacitor and solid state trigger, connected to an axle decoupling

electromagnet as for example described herein. Yet another embodiment is a power axle decoupler comprising one or magnets that couple one axle rotation to another and a stored charge trigger device that dumps stored charge into an electromagnet to at least partially uncouple the two axles. The term "power" in this context means at least 1 horsepower, preferably at least 3 horsepower, more preferably at least 5 horsepower, and in embodiments such as the use with larger boat engines, at least 25 horsepower.

The rapid pulsed electromagnet brake described here also may be used independently without an axial connector or torque converter. For example, the brake may be used on a downstream shaft connected to an electric motor, and can help the motor stop by asserting magnet field(s) perpendicular to the shaft rotation axis in a manner that opposes permanent magnets attached to the shaft. In yet another embodiment, a motor is connected to a propeller via a shaft that can twist around the axis of rotation. The pulsed electromagnet rapidly stops the propeller while the motor stops more slowly, and induces a torsional stress in the flexible shaft.

Although the above description focuses on rapid stopping of propellers, the same materials and methods are intended for use in other systems as well, such as farm machinery, other industrial machinery, other vehicles and the like. Other permutations of embodiments will be appreciated by a reading of the specification and are within the scope of the attached claims.

Example 1

This example demonstrates a typical arrangement wherein multiple permanent magnets are placed at close mutual proximity but on opposite faces of two flat flanges that are connected through a ball bearing. The bearing is a 3 inch bore 4 inch outer diameter ball bearing assembly from Scheerer Bearing Corp. of Horsham, Pennsylvania (catalog No. XW3). The bearing is located in grooves approximately 3/8ths inch thick at the center of two 8 inch diameter 3/4 inch thick aluminum plates. Each plate is connected in its center to a 0.75 inch spindle 6 inches long. Near the periphery of each aluminum plate, on the side with the attached spindle, 6 rectangular indentations one inch square and 5/8 inch thick equally spaced around the plate and starting 1/4 inch

from the outer edge are made. Each indentation is designed to hold a 0.5 inch thick one inch by one inch neodymium boron magnet that will be set with glue. The magnets are 0.5 inch by 1 inch by 1 inch item number NB006N-35 obtained from All Magnetics, Inc. (Anaheim California). The face plates are placed with their flat sides together and spindles out, with the bearing assembly sandwiched between them. Then, a magnet is glued to the outside surface of one face plate with the north pole facing down. A magnet is glued to the backside of the opposite surface face plate with the south pole facing down such that the two magnets attract each other. Then, 180 degrees away on the discs, magnets are similarly added. This is continued until all magnets have been added and the two flat faces are held together by strong magnetic fields. The spindles are mounted in roller bearings in a frame to maintain their position while allowing rotation.

An electric motor of approximately one horsepower is connected to one spindle and a propeller in a tank of water is connect to the other spindle through a shaft. Power is applied at a low level and the propeller turns at the same rpm as the motor. As the power is increased to the motor, the propeller speed progressively becomes lower than the motor speed.

<u>Example 2</u>

In this torque converter example, multiple permanent magnets were placed at close mutual proximity but on opposite faces of two flat flanges that are connected through a ball bearing. The bearing is a 3 inch bore 4 inch outer diameter ball bearing assembly from Scheerer Bearing Corp. of Horsham, Pennsylvania (catalog No. XW3). The bearing was located in grooves at the center of two 6 inch diameter 3/4 inch thick aluminum plates. Each plate is connected in its center to a 1 inch aluminum spindle 6 inches long. Near the periphery of one aluminum plate, on the side with the attached spindle, 8 round holes 3/4 inches in diameter were equally placed around the plate approximately 0.07 inches from the outer edge. A second plate was made the same way but with 9 round holes. Each hole is sized to hold a 0.75 inch diameter, 0.50 inch thick neodymium boron magnet that was hammered in and set with glue (the first plate

had magnets with south pole out, and the second plate had magnets with north pole out). The magnets were obtained from All Magnetics, Inc. (Anaheim California). The face plates are placed with their flat sides together and spindles out, with the bearing assembly sandwiched between them.

A Briggs & Stratton permanent magnet (48 volt 150 amp DC) motor was coupled to each shaft end. A 0 to 48 volt power supply energized one motor and different resistive loads (long extension cords with shorts at the end) were connected to the output of the other motor. Current and voltages at each motor were monitored and each shaft speed was measured. By varying the input power to the drive (upstream) motor, a discontinuous relationship with output power was demonstrated. In one experiment two torque conversion ratios were obtained over a wide range of driving voltage only when heavily loaded. At up to eight volts of drive voltage, the output voltage (rpm) increased at a linear rate. Above 8 volts a different and second linear relationship was established with a different torque transfer ratio. This dual gearing mechanism was not seen at low loading ratios and indicates an automated transmission that can be adjusted by adjustment of magnetic fields.

<u>Example 3</u>

In this axial connector example, two permanent magnets were placed at close mutual proximity but on opposite faces of two flat flanges that are connected through a ball bearing. The bearing is a 1.875 inch outer outer diameter 1.275 inch bore needle bearing assembly with a 0.075 inch thick needle bearing. The bearing was located in grooves at the center of two 3.75 inch diameter 1/2 inch thick aluminum plates. Each plate is connected in its center to a 1 inch aluminum spindle 6 inches long. Near the periphery of each aluminum plate and opposite each other, 2 round holes 0.5 inches in diameter were placed with their outer edges approximately 0.05 inches from the outer edge of the aluminum plate. Neodynium magnets 0.5 inches diameter and 1 inch long were placed into each hole with their surfaces flush with the flange surface opposite the attached spindle. The face plates were placed with their flat sides together and spindles out, with the bearing assembly sandwiched between them. A third plate with axle is

prepared with 3/4 inch diameter magnets and replaces one of the plates, for increased torque transfer. Four electromagnets are made and fixedly positioned close to the backside (away from the bearing side) of one of the plates. Upon energizing the force holding the plates together is weakened.

This connector demonstrates coupling between the two shafts. Upon exceeding the coupling strength, the two shafts rotate. Coupling strength can be decreased by at least 20%, 50%, 75%, 90% or more by application of an electromagnetic field. Application of such field acts to uncouple a propeller, attached at one shaft, from a motor, that is indirectly coupled to the second shaft.

Other embodiments will be appreciated by a skilled artisan upon reading the specification and are intended to be within the scope of the claims. All cited documents are specifically incorporated by reference in their entireties. Priority documents 60/445,249 filed 2/6/03 "Magnetic Torque Converter Particularly for Watercraft," 60/474957 filed 6/03/03 entitled "Magnetic Torque Converter," 60/433591 filed 12/16/02 entitled "Beverage Holders with Passive Cooling," 60/431200 filed 12/06/02 entitled "Propeller Control for Electronic Propeller Circuits," and utility application 10/620618 filed 7/17/03 entitled "Efficient Control, Monitoring and Energy Devices for Vehicles such as Watercraft" are incorporated by reference in their entireties.